RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #7

UAT Gain Antenna, Ground Station Sensitivity, and Link Budget Update

Prepared by George Cooley
and Tom Mosher

UPS Aviation Technologies

SUMMARY

This paper revisits the UAT link budget, shows line-of-sight range limits at various altitudes, roughly classifies the altitude limits of a number of aircraft, and explores various means of improving sensitivities of receiving stations.

1. Introduction

The 5/8-wave antenna pattern for airborne applications was measured. Next the theoretical line-of-sight distances for various altitudes are tabulated. The altitudes incorporated into the table correspond to natural break points in the National Airspace System, which correspond to ICAO standards. The service ceiling limits of various classes of aircraft were also tabulated to help better identify natural breakpoints in equipage classes. Next a link equation based on the minimal transmitter power to meet the worst case 150 NMI surveillance criterion is presented. Finally, various means of improving ground station receiver performance are discussed.

2. Airborne Antenna Gain Measurements

To see how the theoretical antenna gain predictions match reality, measurements comparing the actual gains of ¼ wave and 5/8 wave antennas where preformed. Joe Klein along with his staff at AeroAntenna tested and analyzed the radiation performance of the 0.625 and 0.25 lambda monopoles. The measurements were done at 2.44 GHz. At this frequency when scaled to 981 MHz, a 9-inch ground plane appears as a 2-foot ground plane.

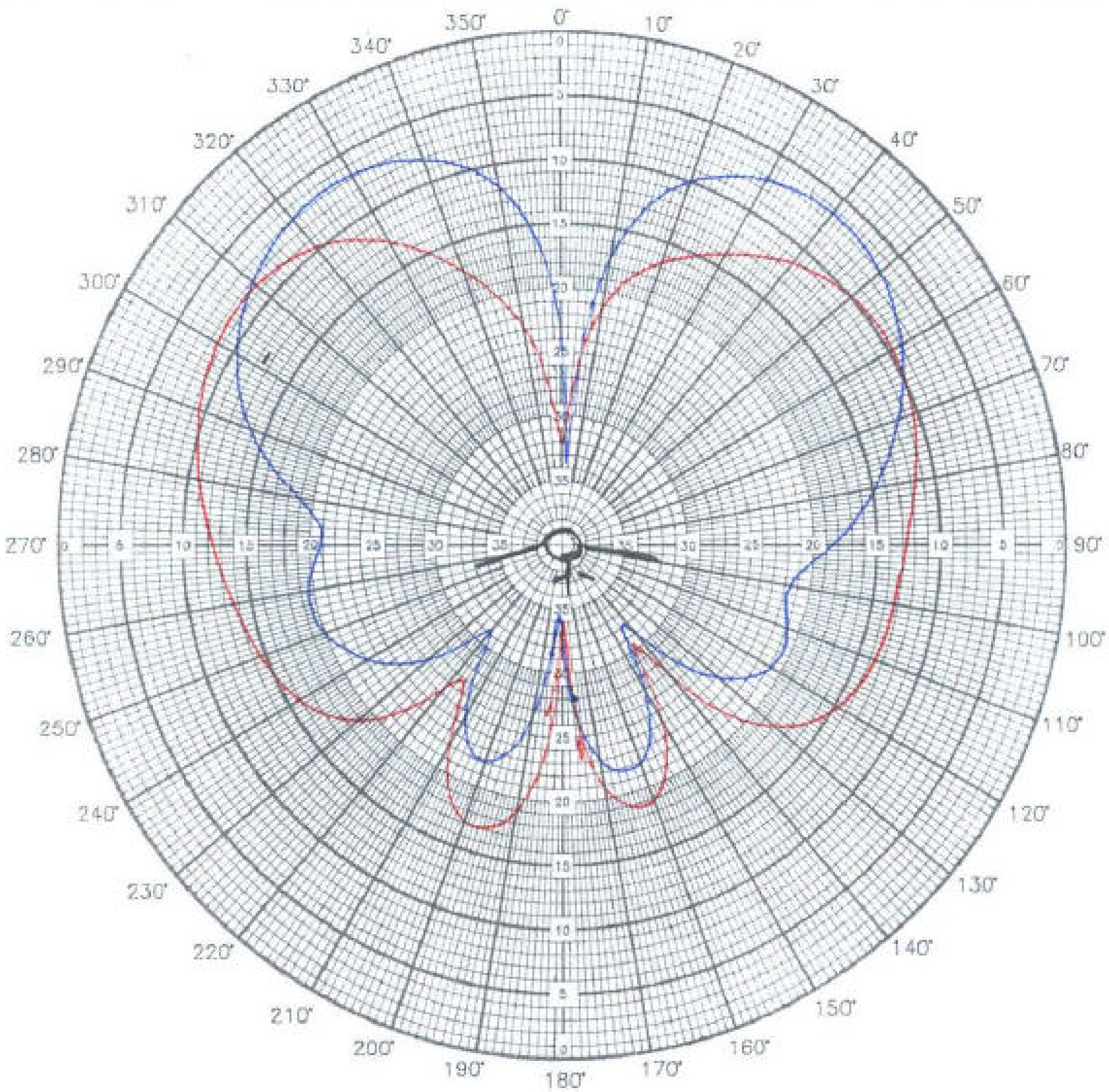
Preliminary results are attached in the figure on the next page. The 5/8 wave is plotted in blue, while the ¼ wave is plotted in red. Only the pattern around the roll axis of the airplane was made. No azimuth plots are available yet, but are expected to be uniform. The zero degree point corresponds to the top of the aircraft while 180 degrees faces the ground. The antenna is mounted on top. To get the pattern of a bottom mounted antenna, just flip the plot.

In the roll plane, the 0625 Lambda antenna affords no advantage in all but the 15 to 45 degree sectors to the left or right of the top (zero degree point). As a matter of fact, the gain of the 5/8 Lambda antenna actually drops in all other sectors compared to the ¼ wave monoploe in the roll axis plane.

For now, we will assume a ¼ wave monopole in our link budget, with no gain. The ground station antennas currently have 8 dBi of gain.

PROJECT NO. monopole antenna
ANTENNA TYPE passive S/N
FULL SCALE FREQUENCY 2.44 GHz
POLARIZATION linear
ANTENNA MOUNTING 9" ground plane

MODEL SCALE
MODEL FREQUENCY
PLANE TYPE
FILE NO.
ISO. LEVEL 12.5 dBi



AeroAntenna Technology Inc

DATE August 13, 2001 (19:14)
TESTED BY Phi Hoang
Q.C. DATE
VARIABLE ANGLE ϕ ( ), θ ( )
CONSTANT ANGLE ϕ = θ =

θ 0° X	ϕ 0°	θ 90°
90° 90°	90° 270°	180° 0°
L 180° R	L R 180°	90°

REMARKS: Red = .25 lambda Blue = .625 lambda

3. Line of Sight Distances vs. Altitude

The table below depicts line-of-sight distances at altitudes that correspond to various boundaries within the airspace structure. The heaviest traffic is typically found inside of class B, C approach control airspace. Both feed into Class D, the airport surface area. Consequently, class D has heavy concentrations of traffic converging to and diverging from its runways.

Altitude (ft)	Line-of-Sight Range (NMI)
2,500 Top of airport surface area- class D	61
4,000 Top of most class C airspace	87
7,500	106
8,500	113
10,000 Top of most class B airspace	123
12,500 Begin oxygen if > 30 minutes	137
14,000 Ox required continuously for crew	145
15,000 Continuous Ox for passengers	150
18,000 Beginning of class A airspace	165

It is interesting to note, that a very large percentage of normally aspirated piston driven single and twin engine airplanes operate below 12,500, which corresponds to a maximum line-of-sight of just 137 nautical miles.

To help the group better understand where various types of airplanes operate, below are some rough classifications of the altitude limits (service ceilings) of different types of aircraft (obviously all of them are capable of operating near the ground).

10 – 15,000 feet	Normally aspirated piston singles and twins
16 -- 25,000 feet	Turbocharged piston singles and twins
20 – 29,000 feet	Turboprops
30 -- 38,000 feet	Low end business jets
33 -- 38,000 feet	Most Airliners, depending on their weight
40 – 55,000 feet	High end business jets
> 55,000 feet	Concorde and space shuttle

4. Air-to-Ground low power Link Budget

The following worksheet shows a link budget for air-to-ground performance, using the lowest limit of ADS-B transmitter power.

Link Budget: Air-to-Ground, Low Power Classification

Operating Freq (MHz)	981	MHz
Tx Power at Antenna	7	Watts (minimum)
Air-to Air ADS-B	**Units**	**A0/A1/B1**
Tx Power - EQPT	Watts	11.1
Tx Power - EQPT	dBm	40.5
Feedline	dB	-2
Tx Power - ANT	dBm	38.5
Tx Antenna Gain	dB	0.0
Path	nmi	150.0
Path Loss	dB	-141.2
Rx Antenna Gain	dB	8.0
Signal at Rx Ant	dBm	-94.7
Feedline	dB	-2.0
Rx Signal - EQPT	dBm	-96.7

The received signal threshold for the airborne receiver is specified at 90% Message Success Rate. The performance requirement for the airborne receiver is –94 dBm at the equipment (-91dBm at the antenna, with 0-dB gain assumed, and 3-dB feedline loss). For installation on small aircraft, 2.0 dB of feedline loss is a reasonable requirement, if not perhaps as low as 1.5 dB particularly for the Bottom antenna installation.

The receiver performance threshold for the proposed base station is 2.7 dB more sensitive that for the avionics receiver. This can reasonable be achieved by noting the following factors:

- A high-value receiver can be designed with smaller manufacturing thresholds. Doing so will raise the cost since more effort can be expended in the test and manufacturing process. For example, testing of a batch of narrow bandwidth receivers showed that actual receiver sensitivity is typically –98 dBm but may not hold as production volumes increase.
- The worst case distance of the link equation is driven by long range surveillance requirements. What has not been defined is what are the required update rates at long ranges. If we are to compare the UAT system to the current ATCRABS surveillance system, the update rates are approximately every 12 to 15 seconds. Thus message reception requirements for acquisition of long-range targets have not been established, but may require 99th percentile probability of receiving an update at least every 12 seconds. This equates to a Message Success Rate of 35%, rather than 90%. The slope of the MSR curve between the 90% and 35% points gives approximately 1 dB additional margin.

- Base stations will require diversity reception, which can give some additional gain through the statistical independence of the receiver thermal noise, combined with some antenna diversity. For example, if two independent processes each have a success probability of 20%, then the probability of both processes failing is (1-0.20)^2, or 36%. This results in a further lowering of the MSR threshold for diversity reception.
- Even if a base station uses the same exact antenna, by using two identical receivers it is possible to gain almost 3 dB in receiver sensitivity as described in the bullet above.

When combined, these factors show that achieving the desired Rx Signal threshold can be achieved without requiring extraordinary effort. Because there are fewer ground stations than aircraft (and let's hope it stays that way), the added cost of making a more sensitive receiver is easier to pass along to ground stations.